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Java-Powered Virtual Laboratory for Nonlinear Structural Dynamic Analysis

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Summary

A Java-Powered Virtual Laboratory (VL) has been developed for conducting nonlinear dynamic analysis of buildings and has been made available on the internet (http://cee.uiuc.edu/sstl/java). This virtual laboratory provides students and practitioners with a means to interactively gain fundamental understanding and intuition about earthquake engineering and structural dynamics. By accessing this on-line software, remote users are able to analyze buildings with a different number of stories using various structural models and design parameters. Dynamic analysis of the structure can be performed using four historical earthquakes, as well as a sinusoidal excitation. Animation of the structural responses is also provided to visualize the dynamic behavior of the building.

Introduction

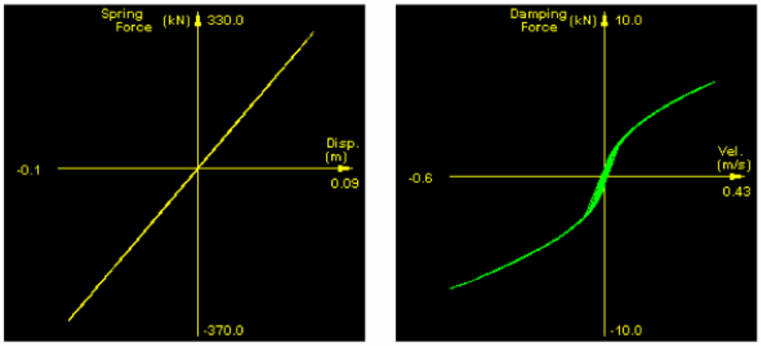
Educators must always strive to better prepare the next generation of structural engineers to understand and effectively deal with the design of earthquake resistant structures to reduce the associated human and financial losses. One of the challenges of teaching students about the fundamentals of earthquake engineering is giving them an intuitive understanding of the dynamics of structures. Demonstrating the concepts of dynamics using static chalk boards or books is difficult. The best approach is through hands-on laboratories. Unfortunately, few instructors have the necessary facilities readily available to demonstrate structural dynamic concepts. This Java-Powered Virtual Laboratory (VL) provides a means for online interactive experiments and is intended to increase understanding and provide a conceptual "feel" of dynamic analysis and design (Dargush et al., 2003).

In this nonlinear structural dynamic analysis VL, users are provided wide flexibility to perform dynamic analysis. Users can choose the number of stories, as well as select the floor mass, stiffness, and damping coefficients for each story. Four nonlinear models are provided to portray the behavior of the structure. The same type of nonlinearity is employed for all stories, but the parameters defining this nonlinearity can be varied for each story. Sinusoidal and four historical earthquake excitations can be chosen for conducting the dynamic analysis. Additional features of this VL include graphically comparing dynamic analysis results of different nonlinearities and animating the response using a virtual building. The user friendly interface helps the participants to understand advanced topics more easily and effectively.

Methodology

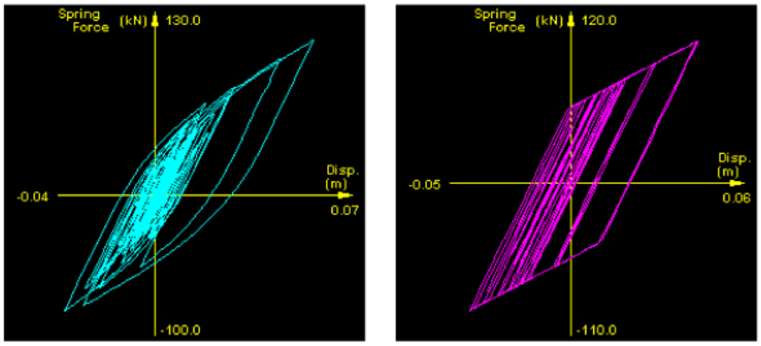
This VL was programmed using Java. The Java programming language (Newman 1996) offers significant advantages because of its minimal dependence on the operational platform. Therefore, this VL can be accessed universally through internet. The Java language also requires a minimum amount of administration maintenance for the VL once it has been developed and published on the internet. If additional updates are required, they can be made locally and put on the internet. When remote users access this software the next time, they will automatically download and run the updated version. In addition, the VL's interactive interface, optimized with Java programming, significantly increases the efficiency of presenting and, in turn, understanding of a wide range of topics in earthquake engineering.

Four types of nonlinear models are provided in this VL to describe the structural dynamic behavior. These nonlinearities (shown in Figure 1) include: (i) linear stiffness and linear viscous damping; (ii) linear stiffness and nonlinear power-law damping; (iii) hysteretic stiffness using the Bouc-Wen model and linear viscous damping; and (iv) hysteretic bilinear stiffness and linear viscous damping. For the first two types of nonlinearities, buildings behave as linear elastic structures. However, damping remains linear for type (i), and type (ii) follows the nonlinear power-law with respect to the velocity. The Bouc-Wen model and hysteretic bilinear nonlinear model are widely employed for modeling nonlinear behavior of concrete and steel structures. By choosing various nonlinearities, users are able to analyze different types of structures using this software.



Linear Stiffness Model – Spring Force vs. Displacement

Nonlinear Power-Law Damping – Damping Force vs. Velocity



Bouc Wen Model – Spring Force vs. Displacement

Hysteretic Bilinear Model – Spring Force vs. Displacement

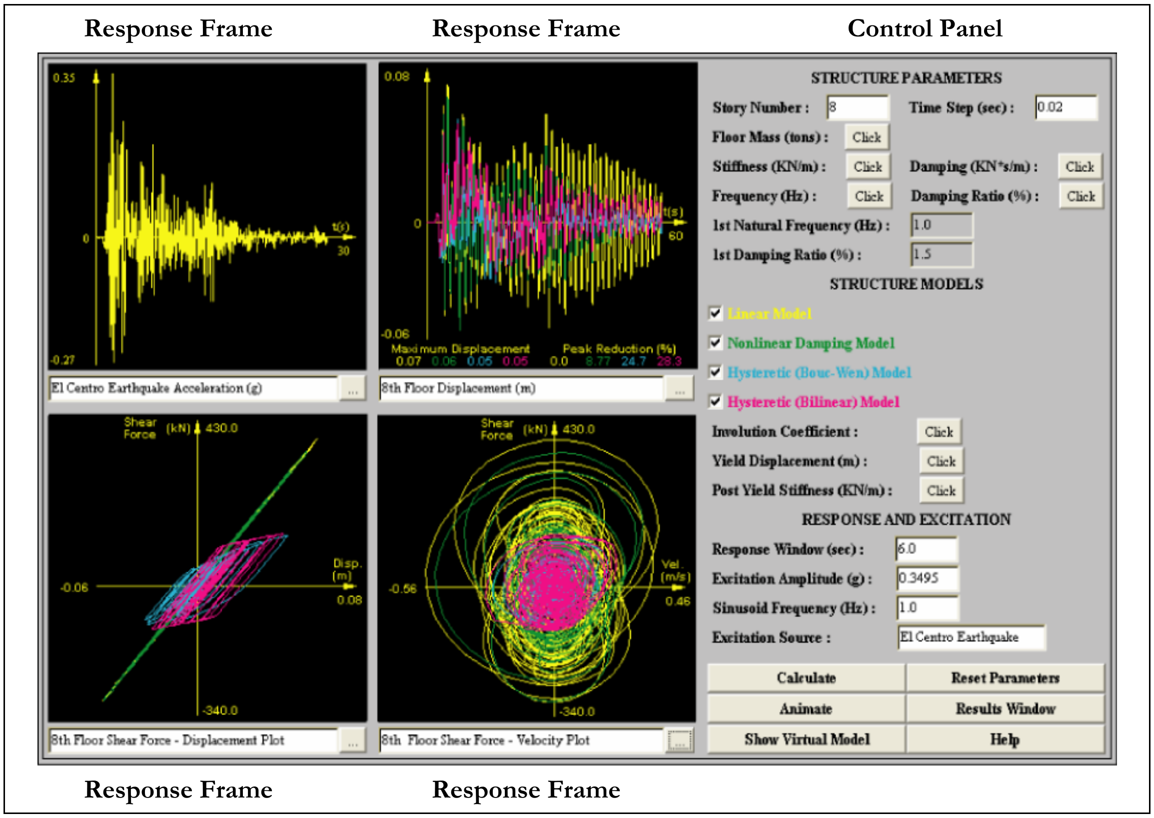
Figure 1. Typical relationship between force and response for different nonlinearities

Computational analysis of the dynamic problems in this virtual simulation utilizes several state-of-the-art numerical algorithms. The Generalized α method was employed to solve the hysteretic bilinear stiffness problem, and the Runge-Kutta method was applied to handle all other linear and nonlinear analysis (Tedesco et al., 1998; Belytschko and Hughes, 1983; Berg, 1989). These computation algorithms were first verified by programming in Matlab and then translated into Java. The book, *Numerical Recipes* (Press et al., 1987), was very helpful for this translation. It is worth noting that the time step of numerical algorithms is important in conducting an accurate dynamic analysis. A smaller time step might be needed as the number of stories increases. The time step in this VL can be specified and the earthquake data are re-sampled when the time step is changed. Accurate results have been obtained by using these numerical methods.

Virtual Laboratory Overview

The interface of the VL is provided in Figure 2. There are four response frames on the left of the user interface. On the right, there is a panel to control the structural analysis and input parameters. There is also an animation panel which provides the animated response. This panel is shown in Figure 3. The control panel and animation panel are interchanged with each other by clicking the "Show Virtual Model" or "Show Control Panel" button located at the lower corner of each panel. A description of each of these components is given below.

The control panel allows users to design and analyze the structure. The number of stories in the building can be changed, and the time step can be modified as well, depending on the calculation requirements. A few default time steps have been preset for different story numbers as a


Response Frame Response Frame Control Panel

El Centro Earthquake Acceleration (g)

8th Floor Displacement (m)

8th Floor Shear Force - Displacement Plot

8th Floor Shear Force - Velocity Plot

STRUCTURE PARAMETERS

Story Number : 8

Time Step (sec) : 0.02

1st Natural Frequency (Hz) : 1.0

1st Damping Ratio (%) : 1.5

STRUCTURE MODELS

☑ Linear Model

☑ Nonlinear Damping Model

☑ Hysteretic (Bouc-Wen) Model

☑ Hysteretic (Bilinear) Model

RESPONSE AND EXCITATION

Response Window (sec) : 6.0

Excitation Amplitude (g) : 0.3495

Sinusoid Frequency (Hz) : 1.0

Excitation Source : El Centro Earthquake

Response Frame Response Frame

Figure 2. Java-powered virtual laboratory

guideline. Structural parameters, including floor mass, story stiffness and damping coefficients, can be varied by clicking the selection button following the label. A dialogue box (Figure 4) will open when the selection button is pushed. Modal properties, including natural frequency and damping ratio, are automatically computed when structural parameters are changed. These properties can be found by clicking the selection button following the label as well. For convenience, the first natural frequency and the damping ratio are also shown in the control panel.

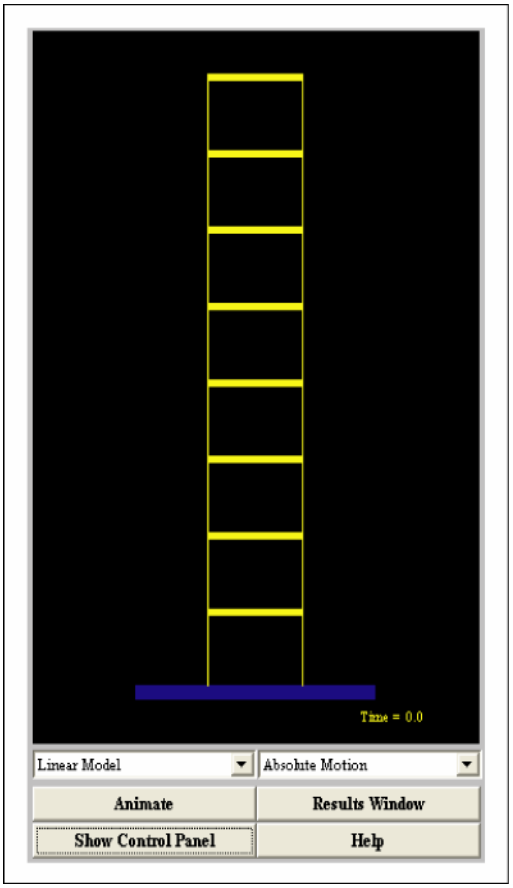
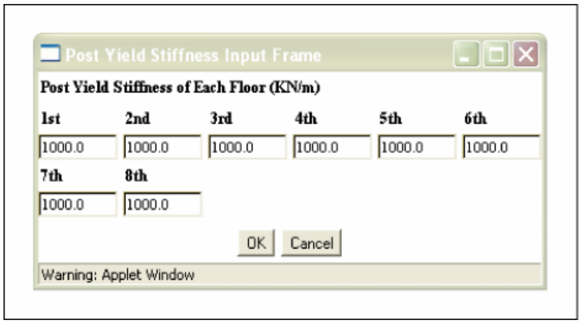


Figure 3. Animation panel



Post Yield Stiffness of Each Floor (KN/m)

1st	2nd	3rd	4th	5th	6th
1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
7th	8th				
1000.0	1000.0				

Figure 4. Post yield stiffness input dialogue box

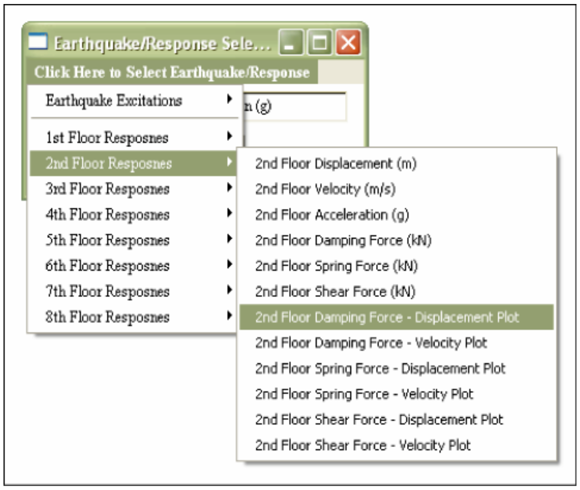


Figure 5. Response selection dialogue box

Users can describe the structure using four different analytical models, which can be selected by clicking the check box under the label "Structural Models," and they can choose either one or multiple nonlinearities to conduct dynamic analysis. The associated parameters for these models, including an involution coefficient for nonlinear damping model, yield displacement and post yield stiffness for nonlinear stiffness model, can be changed in the dialogue box brought up by clicking the selection button (see Figure 4).

Users are also able to control the excitations and the manner in which animation is shown by modifying the related parameters in the control panel. The excitation amplitude can be changed, and the frequency component of the sinusoidal excitation is also variable. The value in the "Response Window" controls how many seconds of the response/earthquake will be displayed during the animation in response frames. The name of the current excitation is always displayed following the label "Excitation Source" in the control panel.

After all the parameters have been input, users can push the "Calculate" button at the lower left corner of the control panel to conduct the dynamic analysis. An animation button is also provided to show the time history of the response. All parameters in the control panel are reset to the default values by clicking the button "Reset Parameters." By pushing the "Show Virtual Model" button, users can toggle between the control panel and the animation panel to help visualize the dynamic response using an animated virtual building. Other important buttons provided are "Result window" and "Help. "

Calculated results are shown in the response frames. The functions of these response frames are identical, except that the top left frame can also display the earthquake excitation. There is a selection button at the lower right corner of each frame. For the top left frame, this selection button brings up a dialog box (shown in Figure 5) for the user to select the earthquake excitation or response to display. For the other three response frames, the selection button brings up a similar dialog box for a response selection only. The currently displayed signal is shown in the text field under the plot in each of these frames.

Various analytical results can be displayed in these response frames. The top right response frame shows an example of the time history response. In this example, the 8th floor inter-story drifts for all the selected structural models are displayed simultaneously. It also shows the maximum response values and the corresponding peak reduction factors, which is the reduction relative to the linear elastic case. By seeing the time history and peak reduction factor for different nonlinearities simultaneously, users can easily appreciate the difference between these nonlinearities under the current excitation. Similar time history plots for relative velocity, absolute acceleration, spring force, damping force and shear force are also readily displayed by clicking the selection button in each of the four frames. The bottom two response frames demonstrate relationships between shear force and displacement, and between shear force and velocity. Similar plots for spring force and damping force can also be shown by clicking the selection button in any one of these four frames.

Conclusions

A unique Java-Powered Virtual Laboratory has been developed to facilitate the understanding of a wide range of topics in earthquake engineering and dynamic analysis. Participants are expected to gain fundamental understanding of these topics by conducting online numerical experiments using this interactive software. This virtual laboratory provides an excellent alternative way for students and practitioners to develop their knowledge of earthquake engineering. By designing this virtual laboratory using Java programming, this software can be accessed universally through the internet. Other available virtual laboratories, including structural control using tuned mass dampers (TMD) and hybrid mass dampers (HMD), and base isolation using linear and nonlinear devices, can be found at *http://cee.uiuc.edu/sstl/java*.

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